

The Optical Polarization and Warm Absorber in IRAS 17020+4544

Karen M. Leighly

Columbia Astrophysics Laboratory, 538 West 120th Street, New York, NY 10027, USA,
leighly@ulisse.phys.columbia.edu

Laura E. Kay

Department of Physics and Astronomy, Barnard College, Columbia University, New York, NY
10027-6598

Beverley J. Wills, D. Wills, & Dirk Grupe

McDonald Observatory and Department of Astronomy, University of Texas at Austin, TX 78712

ABSTRACT

We report the detection of ionized absorption in the *ASCA* spectrum of the narrow-line Seyfert 1 galaxy IRAS 17020+4544. Subsequent optical spectropolarimetry revealed high polarization increasing from 3% in the red to 5% in the blue, indicating electron or dust scattering as a likely origin. The broad emission line H α is somewhat less polarized than the continuum, supporting a location of the polarizing material within the AGN. The Balmer line decrement and reddened optical spectrum supports the presence of a dusty warm absorber in this object.

We compared the broad band optical polarization and ionized X-ray absorption of a collection of Seyfert 1 and 1.5 galaxies, excluding classes of objects that are likely to have significant neutral X-ray absorption. Warm absorber objects are generally more likely to have high optical polarization than objects with no detected ionized absorption. This result lends additional support to the idea that the warm absorber is associated with dust and implies either that dust transmission is responsible for at least part of the polarization or that the polarization is revealed because of the dimming of the optical spectrum. Spectropolarimetry of Seyfert 1s generally locates the scattering material inside the narrow-line region and often close to or within the broad line region, consistent with estimates of the location of the dusty warm absorber.

Subject headings: galaxies: individual (IRAS 17020+4544) – X-rays: galaxies – galaxies: active–galaxies: Seyfert–polarization

1. Introduction

ROSAT and *ASCA* observations of Seyfert 1 nuclei produced abundant evidence for highly ionized material in the line of sight. Signatures of the “warm absorber” are present in the X-ray spectra of about half of Seyfert 1 and 1.5s (Reynolds 1997). Recently, it was noticed that the warm absorber is often associated with optical reddening (Reynolds 1997; Brandt, Fabian & Pounds 1996), supporting the idea that the warm absorber may coexist with dust. Dust reddens the UV-optical continuum spectrum, but it can also polarize it. Thus one might expect high optical polarization in Seyfert 1s that show warm absorber features in their X-ray spectra. As part of an archival analysis program of *ASCA* data (Leighly et al. 1997), we discovered evidence for a warm absorber in the narrow-line Seyfert 1 galaxy IRAS 17020+4544. Noting that it also has a red optical spectrum, we strongly suspected a dusty warm absorber would be present. To test the connection between warm absorbers and optical polarization, we obtained spectropolarimetry and confirmed high polarization.

2. Data and Analysis

IRAS 17020+4544 is a member of the IRAS Point Source Catalog (IRAS PSC) and was originally classified as a Seyfert 2 with redshift $z=0.0602$ (De Grijp et al. 1992). The X-ray emission was first discovered in the cross correlation between the *ROSAT* All Sky Survey and the IRAS PSC (Boller et al. 1992). Subsequent higher resolution spectroscopy revealed Fe II lines and $H\beta$ significantly broader than [O III] (Moran, Halpern & Helfand 1996), forcing reclassification as a Narrow-line Seyfert 1 galaxy (NLS1; Osterbrock & Pogge 1985; Goodrich 1989b).

2.1. X-ray Spectral Analysis

IRAS 17020+4544 was observed using *ASCA* on August 29 1995 and the data were retrieved from the archive. Standard analysis procedures were followed (see e.g. Nandra et al. 1997; Leighly et al. 1997 for details) resulting in approximately 33 ks net exposure. The source was bright, about 0.49 c/s in the SIS0. Since our primary interest is in the warm absorber, we report only analysis relevant to that here.

Preliminary fitting indicated spectral complexity in soft X-rays. We fitted a power law plus a narrow iron line to the data above 2 keV, then extrapolated that fit to lower energies, including a neutral absorption column of $N_H = 3.5 \pm 0.5 \times 10^{20} \text{ cm}^{-2}$ measured from the *ROSAT* PSPC spectrum; note that the Galactic column in this direction is $2.2 \times 10^{20} \text{ cm}^{-2}$ (Dickey & Lockman 1990). The residuals in Figure 1 show that the source is absorbed in soft X-rays, and there is an edge near 0.7 keV which is a characteristic signature of the warm absorber (e.g. Reynolds 1997). A power law, narrow Gaussian (to model the iron $K\alpha$ line) and additional absorption model over the

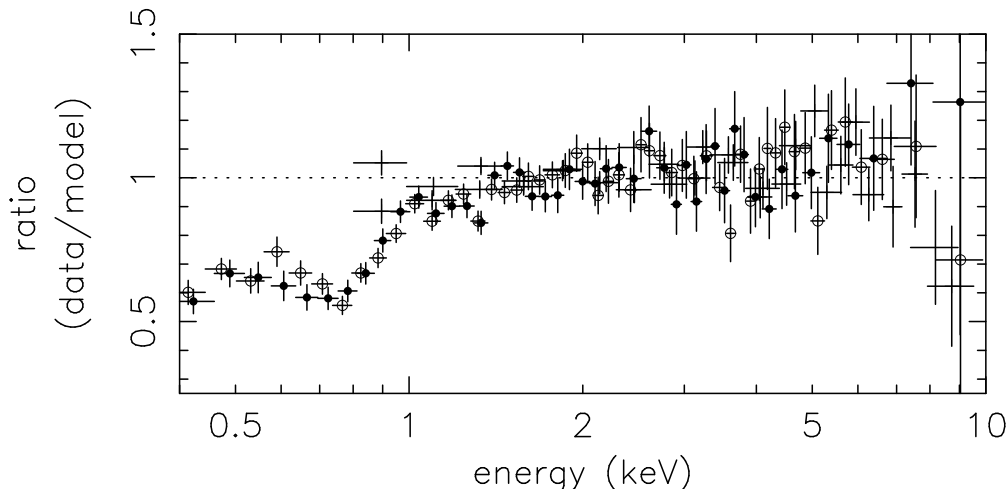


Fig. 1.— The ratio of a power law plus absorption column obtained from *ROSAT* spectrum ($3.5 \times 10^{20} \text{ cm}^{-2}$; Galactic $N_{\text{H}} = 2.2 \times 10^{20} \text{ cm}^{-2}$) model fit above 2 keV and extrapolated to low energies. The open and solid circles correspond to the SIS0 and SIS1 spectra, respectively, while the crosses correspond to the GIS2 and GIS3 spectra.

whole range from 0.4–10.0 keV gives a poor fit with $\chi^2=1167$ for 971 degrees of freedom (d.o.f.). Addition of an absorption edge improves the fit significantly ($\Delta\chi^2 = -131$ for two additional d.o.f.). The edge energy is $0.71 \pm 0.02 \text{ keV}$ (errors are 90% for one interesting parameter), roughly consistent with O VII absorption. Addition of another edge gives no improvement in fit. Following Reynolds (1997) by fixing the two edge energies at 0.74 and 0.87 keV corresponding to O VII and O VIII results in a slightly worse fit than the single edge fit by $\Delta\chi^2 = 8$ with the optical depth of the O VIII edge equal to zero. This suggests that the ionization state of the warm absorber is somewhat low compared with objects studied by Reynolds (1997).

Next we model the warm absorber with the photoionization model *absori* available in XSPEC (Magdziarz & Zdziarski 1995). This model results in a somewhat poorer fit ($\chi^2=1071/969$ d.o.f.) than the edge model but provides an estimate of the ionized column density of $N_w = 2.5^{+0.6}_{-0.5} \times 10^{21} \text{ cm}^{-2}$ and the ionization parameter $\xi = 9.5^{+19}_{-7.6}$. Evidence for emission around 1 keV remains in the residuals. This feature can be modeled as a marginally resolved line at 1.1 keV with equivalent width 75 eV, and then $N_w = 3.5^{+0.6}_{-0.5} \times 10^{21} \text{ cm}^{-2}$, $\xi = 6.1^{+9.8}_{-3.3}$, intrinsic $N_{\text{H}} = 5.5^{+2.1}_{-1.8} \times 10^{20} \text{ cm}^{-2}$ and $\chi^2 = 1016/967$ d.o.f. The 1 keV feature may be similar to the emission features seen in the X-ray spectrum of other NLS1s, possibly a blend of photoionized iron and neon emission lines (e.g. PG 1244+026: Fiore et al. 1997; Ton S180, Akn 564: Leighly et al. 1997).

2.2. Spectropolarimetry

We obtained spectropolarimetry data on IRAS 17020+4544 at the Lick Observatory 3m telescope with the KAST spectrograph (e.g. Martel 1996) and at the McDonald Observatory 2.7m telescope with the Large Cassegrain Spectrograph (e.g. Hines & Wills 1993). Figure 2 shows spectropolarimetry results. The polarization position angle is constant at about 166° and is therefore not shown. We measured the host galaxy axial ratio on the Digitized Sky Survey image to be 0.55 ± 0.02 with position angle $168 \pm 1^\circ$, in good agreement with the polarization position angle. Broad-band imaging polarimetry measurements with the McDonald Observatory 2.1-m telescope (Grupe et al. 1997) agree in position angle and in the blue but find lower polarization in the red, probably a result of a larger aperture (7.4'' diameter compared with 2'' slits.) We find (filter–effective wavelength–percentage polarization): U–3600Å– 7.1 ± 3.1 ; CuSO4–4200Å– 3.93 ± 0.35 ; none–5700Å– 2.42 ± 0.18 ; RG 630–7600Å– 1.68 ± 0.20). The spectropolarimetry data indicate that the continuum is polarized at about 3% at the red end increasing to 5% at the blue end. The Balmer lines of H α (and perhaps H β) are less polarized than the continuum average, and the [NII] $\lambda\lambda$ 6548,6583 and [OIII] $\lambda\lambda$ 4959,5007 lines may be slightly less polarized than the Balmer lines. In polarized flux the [OIII]/H β ratio is lower than in direct flux and the [NII] λ 6583/H α ratio may also be slightly lower. The direct and polarized flux widths are reasonably similar in H α ; this is probably true but more difficult to measure in H β . Since the widths of the Balmer lines are similar in polarized and direct flux, and the continuum polarization clearly rises to the blue, we can conclude that reflection by dust or electrons is a likely cause of the polarization, although dust transmission may contribute (see below). This is in agreement with a sample of NLS1s observed by Goodrich (1989b). We note also that high polarization is often found in dusty IRAS-selected AGN (e.g. Wills & Hines 1997).

In direct flux, H α /H β = 8.4. Following Reynolds et al. 1997, for a Galactic interstellar medium dust to gas ratio and assuming intrinsic ratio of 3.1 (Veilleux & Osterbrock 1987), we derive $4.0 \times 10^{21} \text{cm}^{-2}$ for the column density, roughly consistent with the ionized column density measured in the X-rays. This result supports the association of the dust with the ionized gas, and suggests that the broad lines are seen through most of the obscuring screen. In polarized flux H α /H β was ~ 3.5 ; however, statistics were not good enough to measure the lines accurately. The polarized flux spectrum is nearly flat, as the reddening seen in the direct flux spectrum cancels the rise to the blue in P .

3. Discussion

Based on the discovery of the warm absorber in IRAS 17020+4544, we postulated high polarization and found that it was present. We collected data from the literature to test the generality of the association between the presence of the warm absorber and high optical polarization.

The sample was chosen carefully. Because our goal was to test the association of the *ionized* absorber with optical polarization, we excluded objects in which high *neutral* columns are expected, since dust associated with the neutral column could also produce polarization. Therefore, we included Seyfert 1s, 1.5s and narrow-line Seyfert 1s, but excluded Seyfert 1.8s, 1.9s and NELGs, which are often reddened, suffer X-ray absorption and lie in galaxies viewed at high inclination angle (Goodrich 1989a, 1995; Lawrence & Elvis 1982; Mushotzky 1982; Forster et al. 1997). We also excluded objects at low Galactic latitude to avoid polarization by the Galactic interstellar medium; nevertheless this contributes a systematic error of about 0.3–0.4%. Optical polarization of Seyfert 1s is correlated with the axial ratio of the host galaxy (Berriman 1989; Thompson & Martin 1988) so we exclude objects with low b/a (IC 4329a, Mrk 1040) unless differences in line and continuum polarization indicates the absorber is inside the AGN (3A 0557-383; Brindle et al. 1990b). Broad-line radio galaxies are also excluded since a contribution to their polarization may come from a nonthermal component (Rudy et al. 1983; Antonucci 1984), and they also sometimes show weak intrinsic neutral X-ray absorption (Wozniak et al. 1997).

The resulting sample comprised all the objects from Reynolds (1997) excluding those listed above, MR 2251-178, for which we found no polarization measurement, and 3C 273. We included also Mrk 766 (Leighly et al. 1996), IRAS 13349+2438 (Brandt et al. 1997), 3A 0557-385 (Turner, Netzer & George 1996), NGC 7213 (Otani 1996) and Akn 120, I Zw 1, Mrk 478, Mrk 279, Mrk 110 (from the archive and analyzed by KML following Section 2.1 and Reynolds 1997; warm absorbers were not detected in these objects). Broad-band polarization measurements in the band 3800-5600Å which is blue enough to avoid dilution by cool starlight, were used. The values were predominantly taken from Berriman (1989), except for Mrk 766 (Goodrich 1989b), IRAS 13349+2438 (average of B & V band, Wills et al. 1992), Mrk 335 and Mrk 110 (Berriman et al. 1990), and IRAS 17020+4544, presented here.

The polarization versus column density is shown in Figure 3. Open symbols mark the ionized absorber column density in objects in which a warm absorber was detected, while solid symbols plot the excess neutral column density over Galactic in objects with no detectable warm absorbers. Objects with no measurable excess neutral column are assigned $N_H = 1 \times 10^{20} \text{ cm}^{-2}$, approximately the level of systematic error from *ASCA* spectra, and errors equal to $\max\{\text{fit upper limit}, 1 \times 10^{20} \text{ cm}^{-2}\}$. The neutral column density of the warm absorber objects is not taken into account, since the warm column density is very much larger than the cold column density in all cases except 3A 0557-383. This plot shows that objects with high optical polarization ($\gtrsim 1\%$) are very likely to have warm absorbers. However, the converse is not generally true; i.e. objects with high ionized columns don't necessarily have high optical polarization. Two notable examples, NGC 3783 and NGC 3516, are discussed below. Note that scatter is expected since the warm absorber can in principle respond rapidly to ionizing flux changes while dust properties are expected to change on much longer time scales. Nevertheless, the KS test indicates a different distribution of polarization of warm and cold absorber objects with 99% confidence.

Brandt, Fabian & Pounds (1996) first speculated that the high degree of optical reddening

in IRAS 13349+2438 could be reconciled with the bright soft X-ray emission only if the gas associated with the dust responsible for reddening were ionized. Reynolds (1997) found a strong relationship between the reddening of the optical spectrum and the optical depth of the ionized absorber O VII edge in a sample of 24 AGN. In a sample of bright soft X-ray selected objects, Grupe et al. (1997) found that significant polarization occurred in objects in which the degree of optical reddening was too high to be consistent with the relatively unabsorbed soft X-ray spectra unless the gas were ionized. These results all support the association of the warm absorber with dust.

Generally speaking, in Seyfert 1s and 1.5s, the narrow emission lines are less polarized than the broad lines which are in turn less polarized than the continuum, indicating that the scattering material is interior to the narrow line region (NLR). Many Seyfert 1s and 1.5s show changes in position angle across the broad emission lines (e.g. Goodrich & Miller 1994; Martel 1996), and variability in the polarization properties on time scales of months to years (Martel 1996; Smith et al. 1997), indicating that the scattering region is not much larger than the broad line region (BLR). If the dust is associated with the warm absorber, it must be located far enough from the nucleus that the dust does not evaporate. MCG-6-30-15 apparently has an inner and outer warm absorber (Otani et al. 1996), and it is probable that the outer one is dusty (Reynolds et al. 1997). Since it is unlikely that the dust could condense out of ionized gas, a source of dusty gas which can then be ionized is required; this could be a wind off the molecular torus lying at a radius between the BLR and NLR radii in unified models (Reynolds et al. 1997). It has been suggested that dust absorption may naturally result in a line free zone between the BLR and NLR (Netzer & Laor 1993). The narrow “associated” UV absorption lines may originate in warm absorber material (e.g. Mathur, Elvis & Wilkes 1995); since these are superimposed on the broad emission lines, a location outside the BLR is required. These results all support a similar location for the polarizing material and the dusty warm absorber.

The warm absorber measures conditions in line of sight gas. If the same material is responsible for the warm absorber, reddening and polarization, then dust transmission must be responsible for at least part of the polarization. The dashed line in Fig. 3 shows the predicted polarization versus column density for the dust transmission mechanism. We assumed the empirical laws appropriate for the Galactic interstellar medium (Clayton & Cardelli 1988), including maximum polarization $P_{max} = 9\% E(B - V)$, ratio of total-to-selective extinction $R_V = 3.1$, and the N_H -to-reddening relation from Heiles, Kulkarni & Stark 1981. Polarization should lie below this line if dust transmission is the only polarizing mechanism. However, dust and electron scattering may also contribute to the polarization; furthermore, the geometry, grain alignment, dust composition, and dust-to-gas ratio are probably different in the AGN. Another possibility is that high polarization is revealed as a consequence of the suppression of the unpolarized direct (rather than scattered) light by reddening (e.g. Wills et al. 1992). The dotted lines in Fig. 3 show the predicted polarization versus N_H for this model. We assumed that the intrinsic maximum polarization is 7%, seen when the direct continuum is completely attenuated, and that the ratio of scattered to direct light is 0.1

or 0.01 (upper and lower curves, respectively).

While NGC 3516 and NGC 3783 have among the highest ionized column densities ($N_w = 100$ and $204 \times 10^{20} \text{ cm}^{-2}$), they have only moderate polarization ($\sim 0.45\%$ and $\sim 0.80\%$, respectively) and are also not substantially reddened (Reynolds 1997). Perhaps only the inner warm absorber is present or the dust has been destroyed in these objects. Electron scattering could be the origin of the moderate polarization. No strong wavelength dependence is seen in either object, consistent with this idea (NGC 3516: Martel 1996; NGC 3783: Brindle et al. 1990a,b). Goodrich & Miller (1994) find that a maximum of 7% polarization can be obtained in Seyfert 1s when the optical depth $\tau = 1$. The ionized column densities present an optical depth of $\tau = 0.1$ and therefore the observed polarization could be consistent with an origin of free electrons in the ionized gas.

It would be interesting to extend this work to include Seyferts with significant neutral absorption: Seyfert 1.8s, 1.9s, and NELGs. All together, this may support a picture in which the dust, ionized gas and broad emission line clouds have a common origin in Seyfert 1s and intermediate type Seyferts, with decreasing inclination angle reducing the amount of obscuring material in the line-of-sight, but revealing gas of increasing ionization parameter.

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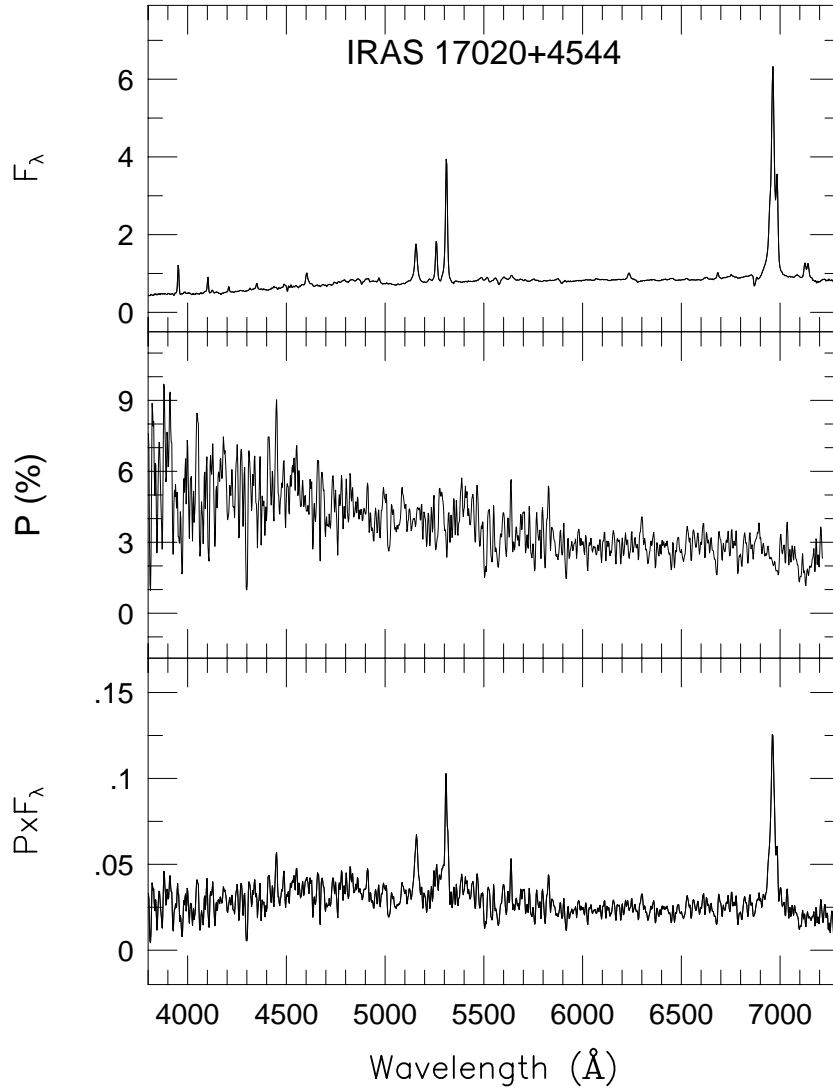


Fig. 2.— Spectropolarimetry of IRAS 17020+4544 uncorrected for reddening or redshift. The Lick data (60 minute exposure on 1997 March 8) were matched to the McDonald data (200 minutes exposure on 1997 April 8 and 10), taking into account small differences in polarization in the red, possibly the result of host galaxy starlight. The flux is in units of $10^{-15} \text{ erg/sec/cm}^2/\text{\AA}$. The second panel is the polarization (strictly Stokes q rotated to position angle 163 degrees), and the third is the corresponding polarized flux. No other corrections were made, as lack of strong stellar absorption lines in the direct flux spectrum suggests little contamination.

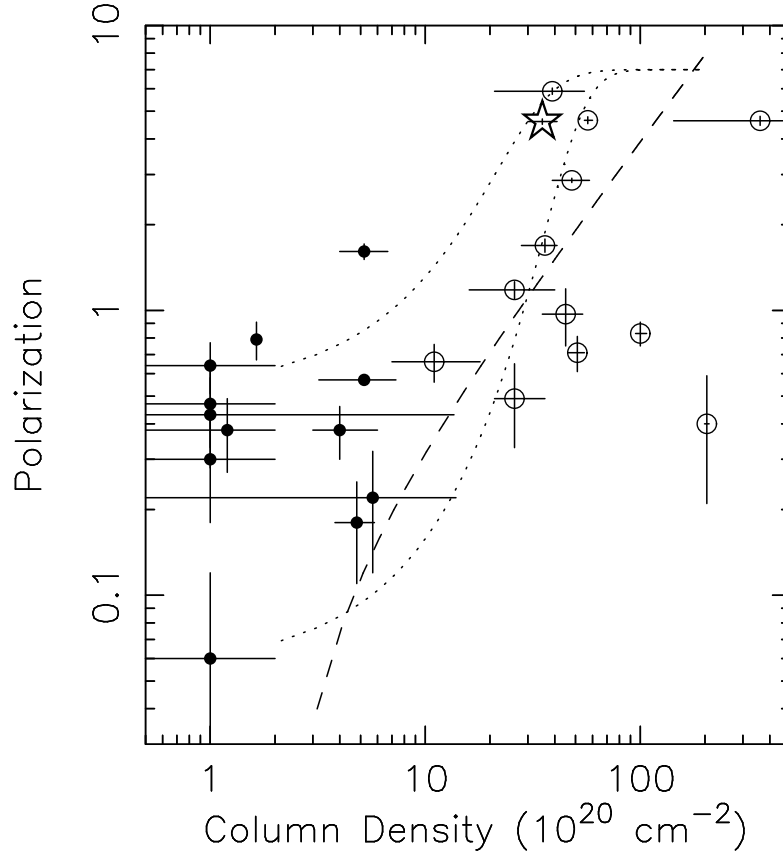


Fig. 3.— Absorption column versus polarization. Open symbols: ionized column density of objects with warm absorbers detected in *ASCA* spectra; solid symbols: excess neutral absorption over Galactic in objects with no detectable warm absorber (see text). The star marks the position of IRAS 17020+4544. Dashed curve: predicted maximum polarization from dust transmission. Dotted curves: predicted polarization from scattering assuming 7% intrinsic polarization and two assumed ratios of scattered to direct flux: 0.1 and 0.01 for upper and lower curves, respectively.

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